Aerosol Microphysics and Radiation Integration

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LONG-TERM GOALS

This long-term goals of this project is the development of systems that support real time global prognostic aerosol and visibility models for the benefit of the Department of Defense and civilian research communities. Aerosol particle light extinction and absorption properties vary considerably by region, and aerosol models struggle with complex and harsh environments. Visibility degradation is a chronic issue in many sensitive parts of the globe, including the Arabian Gulf/Arabian Sea, East Asia, and some parts of the Mediterranean Sea. Along coastal and even some deep ocean regions, dust, pollution and smoke are often present and can dominate Electro-Optical (EO) effects over simple sea salt. In order to account for these varied aerosol species, models such as the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS®[1]) and the NRL Aerosol Analysis and Prediction System (NAAPS) require precise source and sink functions, as well as parameterizations for particle size, chemistry, and optical properties. Similar microphysical data are required for remote sensing systems. A consistent aerosol microphysics and radiation model is necessary if aerosol forecasting systems are to make the leap to satellite data utilization. As the models are so heavily dependent on derived microphysical parameterizations and remote sensing data, this program is deeply involved in the model data assimilation and validation effort. Ultimately, the aerosol parameterizations generated by this research will be transitioned into Navy transport, EO propagation, and visibility models. We provide support to the operational systems when implemented, and assesses model efficacy.

OBJECTIVES

The objective of this program is to investigate, develop, and test aerosol microphysical and radiative properties and parameterizations to be used in Navy aerosol models and remote sensing retrievals. To this end, in FY05 we had 4 primary work areas:

1) Compile and analyze data collected during the UAE[2] campaign. In addition to generating databases of collected data for the science team, this project has three principal work areas. These are a) perform an assessment of dust particle physical and chemical properties in Southwest Asia, b) Explore and derive a model of dust particle mass scattering efficiency, c) evaluate aerosol particle hygroscopic growth.

[1] COAMPS is a registered trademark of the Naval Research Laboratory.

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14. ABSTRACT **This long-term goals of this project is the development of systems that support real time global prognostic aerosol and visibility models for the benefit of the Department of Defense and civilian research communities. Aerosol particle light extinction and absorption properties vary considerably by region, and aerosol models struggle with complex and harsh environments. Visibility degradation is a chronic issue in many sensitive parts of the globe, including the Arabian Gulf/Arabian Sea, East Asia, and some parts of the Mediterranean Sea. Along coastal and even some deep ocean regions, dust, pollution and smoke are often present and can dominate Electro-Optical (EO) effects over simple sea salt. In order to account for these varied aerosol species, models such as the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS?1) and the NRL Aerosol Analysis and Prediction System (NAAPS) require precise source and sink functions, as well as parameterizations for particle size, chemistry, and optical properties. Similar microphysical data are required for remote sensing systems. A consistent aerosol microphysics and radiation model is necessary if aerosol forecasting systems are to make the leap to satellite data utilization. As the models are so heavily dependent on derived microphysical parameterizations and remote sensing data, this program is deeply involved in the model data assimilation and validation effort. Ultimately, the aerosol parameterizations generated by this research will be transitioned into Navy transport, EO propagation, and visibility models. We provide support to the operational systems when implemented, and assesses model efficacy.**		
15. SUBJECT TERMS		

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2) Initiate global satellite data assimilation methods for the development of an aerosol optical thickness analysis using MODIS.

3) Continued data analysis from the Asian Dust Above Monterey (ADAM) field study and use of the CIRPAS Stabilized Radiometer Platform.

4) Continued development of real time visibility analysis and validation tools and development of NIPRNET/SIPRNET aerosol website.

APPROACH

Our approach is to perform simultaneous studies of modeled, remotely-sensed, and field data. Physically consistent sets of particle parameterizations are generated based on all three data sources. Analysis of UAE^2 dust properties focuses on the simultaneous collection of filter, aerodynamic particle sizer and light scattering data collected at the Mobile Atmospheric Aerosol and Radiation Observatory (MAARCO). Aircraft data sets from the mission were also compiled and linked to the extensive network of ground stations.

The data assimilation task focuses on the use of the "bent pipe" data feed where MODIS level 2 and degraded level 1b is made available to NRL with only a few hours latency. MODIS level 2 products are evaluated with the use of the global Aerosol Robotic Network (AERONET) network of sun photometers. Two years of MODIS data was co-located with over 20 shoreline and ocean sun photometer sites. MODIS AOT bias was then evaluated as functions of various environmental conditions including cloud cover, local wind speed, and aerosol microphysical properties.

The focus of the work on ADAM has been on synthesizing surface lidar and sun photometer data, and aircraft radiometric and microphysical measurements to characterize Asian aerosol climatology and vertical structure for model comparison. The CIRPAS Stabilized Radiometer Platform task involved the continued testing, troubleshooting, and use of the platform with the goal of making it a more reliable, robust instrument.

The development of real time visibility analysis and validation tools is performed in conjunction with contacts in the operational Navy METOC personnel, including Fleet Numerical Meteorological and Oceanographic Center (FNMOC) and surface and air warfare units. Operations personnel feedback is utilized in the development and refinement of new products.

Team members supported by this project include J.S. Reid (UAE^2), A. Bucholtz (ADAM and CIRPAS), J. Zhang (Data assimilation), and C. Curtis (Products and tools).

WORK COMPLETED

The primary UAE^2 database has been compiled, and preliminary analysis of aerosol probe and chemistry data including quality assurance has been completed. Additional filter data was analyzed by Neutron Activation Analysis (NAA) to assess the significance of matrix effects in particle chemistry. Aircraft data has been sorted and individual case studies have been derived. Preliminary estimates of dust particle mass scattering efficiency, pollution composition, and hygroscopicity has been made. Significant effort has been made to coordinate these data sets with others on the science team.

As the initial step using MODIS level II aerosol product (MOD04/MYD04) for data assimilation in aerosol forecasting applications, a work unit milestone quantitatively analyzed uncertainties in MODIS data from Terra and Aqua due to near surface wind speed, cloud fraction, and aerosol microphysical properties. Systematical biases in MOD04/MYD04 aerosol optical depth (τ) were estimated and empirical corrections and quality assurance procedures were developed. The residual uncertainty was then parameterized into a master MODIS uncertainty matrix. This was primarily done by examining MODIS data with a combination of AERONET sun photometer data and NOGAPS meteorology fields.

The ADAM aircraft navigational data, meteorological data, and particle probe data was obtained and work is progressing on both merging these datasets with the aircraft radiometer data and correlating them with the surface data from MAARCO. Analysis of the pre- and post-mission calibrations of the radiometers is nearly finalized.

Delivery of a 2nd Stabilized Radiometer Platform was received at CIRPAS, and both units were flown successfully on the Twin Otter during test flights in March. In July, both platforms were again flown on the Twin Otter for a Caltech-led field study investigating the indirect effect of aerosols on marine stratus clouds (Seinfeld, PI). During this study both units experienced failures that required extensive troubleshooting in consultation with the manufacturing company. Both platforms have subsequently been repaired. Despite these failures useful radiometer data was still obtained for the Caltech field study.

New systems were developed for the utilization of available quasi-operational data streams, including MODIS and AERONET data. Assistance was provided to FNMOC for the transition of Slant Path visibility software to operational status. Lastly, frequent dialogs were conducted with CSG 11 (Nimitz) on possible improvements and innovations to EO and visibility products.

RESULTS

Significant progress was made this fiscal year in the analysis and understanding of the Arabian Gulf Environment. Indeed, the UAE2 mission provided the very first comprehensive data analysis set of the EO environment coupled with calibration/validation of satellite and model products. Extensive preliminary analyses and abstracts from the first year of research for this program can be found in the projects first year report (Reid, J. S., S. J. Piketh, R. T. Bruintjes, R. A. Kahn, and B. N. Holben, eds., A Summary of First Year Activities of the United Arab Emirates Unified Aerosol Experiment: UAE^2 , NRL/MR/7530-05-8899, 148 pp, August 1, 2005.). However, there are two topics that are worth discussing here.

First, for the first time the mass scattering efficiency of dust was measured in the Arabian Gulf region. Presented in Figure 1 is a scatter plot of the computed Total Suspended Particulate matter (TSP) mass scattering efficiency versus angstrom exponent (Values of angstrom exponent near 2 constitute when almost all visible light scattering is by fine mode particles such as pollution, values near 0 represent coarse mode dust). For dust dominated conditions, vales of the mass scattering efficiency are at ~0.4 $m^2\ g^{-1}$. Given that these samples were collected in the middle-east near source regions such a low value is not unexpected. But, for periods dominated by pollution, the value of 1.5 $m^2\ g^{-1}$ is approximately half of what it should be (~3 $m^2\ g^{-1}$). This low value is the result of residual dust in the atmosphere that is not optically active in the visible. However, it will be active in the infrared. Consequently, satellite data assimilation schemes that predict only fine mode particles will likely miss this important component and result in an overestimation of infrared visibility.

A second important issue is particle hygroscopicity. Relative humidity over the Arabian Gulf is extremely high-often above 80%. Consequently, hygroscopic growth of pollution particles in this region will dominate visibility. But, given the mixture of pollution in the region, do the more commonly used hygroscopic growth functions hold? A scatter plot of particle hygroscopic growth found at a UAE coastal site is presented in Figure 2. The Y-Axis is the relative amount of light scattering increase versus a dry particle (RH<30%). X-axis is the ambient relative humidity of the atmosphere. So for example, for periods at 80% relative humidity, we found that light scattering increase (and visibility likely decreased) by a factor of two. Despite our findings that pollution in the Arabian Gulf is almost pure ammonium sulfate, these hygroscopic growth curves are more suppressed and are similar to those found off the coast of China. This may result of residual dust or perhaps the presence of some hydrophobic organic species form the petro-chemical industry. Regardless, these measurements suggest that a fairly uniform hygroscopic growth model can be used for most of Asia.

The initiation of the MODIS data assimilation program this fiscal year provided significant advances in our understanding of MODIS aerosol product fidelity. Most importantly, the impact of biases in AOD products due to insufficient cloud screening was for the first time quantified for marine environments. We explored the recently reported relationship between MODIS aerosol optical depth and cloud fraction over remote oceans (Figure 3). We showed that artifacts such as cloud contamination or adjacency effect contribute to the majority of the relationship in clean marine conditions. This cloud fraction effect could result in a 10-20% overestimation in monthly mean aerosol optical depth or aerosol direct forcing values that are derived using MODIS aerosol products over "cloud free" oceans. It may also explain some of the high optical depth values derived by other researchers in the mid-latitude southern oceans. Our conclusions also suggested that covariances of meteorological phenomenon such as wind or humidity in cloudy regions while logical might only account for a minor portion of the ensemble relationship. These findings significantly challenged current thought in the use of satellite data for data assimilation purposes in relatively clean environments.

This analysis was extended further to potential biases in surface reflectance and particle microphysics. For example, we found MODIS AOTs were underestimated at low wind cases and over estimating at high wind cases, which could be related to white foams and the increase in width of glint regions as near surface wind speed increase. Biases are as large as 0.04 at mid-visible wavelengths. In clean marine conditions, this can be as high as a 40% relative error. We also found MODIS to be underestimating over smoke and pollutant aerosol regions and over estimating over dust regions. Biases were on the order of 10-25%. Interestingly, in previous analyses in the community this effect was ignored. By grouping the dust and smoke cases together, a scatter plot along the unity line was generated and all was assumed well with the algorithm. This work has now progressed to a state where in FY06 we can begin the assimilation of MODIS data into NAAPS.

Two interesting findings have emerged out of the ADAM data. First, observational and model data suggest that Iraqi and Saudi Arabian dust, generated from the massive dust storm that occurred at the start of Operation Iraqi Freedom in late March 2003, may have been sampled during ADAM. COAMPS and NAAPS model runs show the dust from southwest Asia being lofted and transported to the west coast of the U.S. (see Figure 5). In addition, preliminary analysis of surface meteorological observations in Asia shows the lack of any significant dust generation in that region during the same time period. Finally, preliminary analysis of the measurements from the surface MPLNET lidar and AERONET sun photometer on MAARCO, and the in situ particle samplers on the CIRPAS Twin Otter, indicate the presence of aerosol layers aloft on April 3rd, the day of the NAAPS predicted arrival of the Iraqi dust on the west coast of the U.S. If the evidence holds up this would illustrate the potential for the long range transport of dust halfway around the world. The second interesting finding from ADAM is the consistent observation during the study that the Asian dust was located in layers of low relative humidity. This was seen in the surface lidar and sounding data, and in the aircraft particle sampler and meteorological data. The implications of this finding for explaining the long-range transport of Asian dust are being investigated.

IMPACT/APPLICATIONS

The most significant impact of this program to the Navy this year is that data collected during the United Arab Emirates Unified Aerosol Experiment (UAE^2) was analyzied to develop a Southwest Asia aerosol model appropriate for electro-optical and wave-optics code runs. For the first time, particle hygroscopicity was measured in the Arabian Gulf-an area of very high humidty. Further, particle mass scattering efficiency and other microphysical parameters were also uniquely measured.

The second component of this project on prepratory research in the delveopment of a real time aerosol data assimilation system for use in prognostic aerosol model (such as NAAPS). This work will eventually yield the world's first operational aerosol optical depth data assimialtion system. We expect this advancement to greatly improve the DoD's ability to monitor and forecast severe visibility reducing events.

TRANSITIONS

All source functions and microphysics products feed directly into NAAPS and COAMPS aerosol modules. As these models have been transitioned to Fleet Numerical Meteorology and Oceanographic and Center (FNMOC) for Navy operational visibility forecasting, associated prodcuts are being transitioned as well. Processed data collected in the UAE^2 will be made availalbe to other DoD organizations for validating and improving EO propagation models.

Fire products (including fluxes and transport data) from the joint ONR 32/NASA Fire Locating and Modeling of Burning Emissions (FLAMBE) project is currently being utilized by Internet Community, Air quality/human health research (University of Kansas Medical Center), Environment Canada – Quebec Region Pacific Northwest Laboratory, Dept. of Energy for ARM program research, State of Chiapas Dept. of Civil Protection for fire assessment, the Texas Environmental Board for regional air quality, and the University of Newcastle, Australia for aviation forecasting, and the Max Plank Institute for Meteorology.

RELATED PROJECTS

This project is closely tied to other work units at ONR Code 325, NRL, NPS, and PMS-405. Products, data assimilation code, and validation work feed directly into the ONR 35 6.2 project Coastal Aerosol Distribution by Data Assimilation (Douglas L. Westphal, PI) for further development of NAAPS as well as 6.1 Base funding projects developing an aerosol componeent to COAMPS (Ming Liu, Shouping Wang). This project is closley tied to the ONR/SPAWAR Rapid Transition Plant project Slant Path Visiblity (FY03-FY05). Systems developed under this work uunit are being immediately being applied to the ONR 35 project on directed energy propagation. Field measurements collected in FY04 in the Arabian Gulf region and analyzed in teh FY05 under this work unitare being used in COAMPS/ NAAPS model assessment (Westphal, Holt). Near-real time remote sensing products also also utalizing this work unit's products.

PUBLICATIONS

(a) Peer review manuscripts in print or press

Honrath, R. E., R. C. Owen, M. Val Martý´n, J. S. Reid, K. Lapina, P. Fialho, M. P. Dziobak, J. Kleissl, and D. L. Westphal , Regional and hemispheric impacts of anthropogenic and biomass burning emissions on summertime CO and O3 in the North Atlantic lower free troposphere, J. *Geophys. Res.,* 109, D24310, doi:10.1029/2004JD005147, 2004. [published, refereed]

O'Neill, N. T., S. Thulasiraman, T. F. Eck, and J. S. Reid, Robust optical features of fine mode size distributions: application to the Québec smoke event of 2002, *J. Geophys. Res*, D1120710.1029/2004JD005157. 2005. [published, refereed]

Reid., J. S., B. Brooks, H. H. Jonsson, K. K. Crahan, D. A. Hegg, T. F. Eck, N. O'Niell, K. A. Anderson, and E. A. Reid, Evaluation of coarse mode sea salt size measurements and parameterizations at a sub-tropical ocean receptor site, *J. Geophys. Res*., in press, 2005. [published, in press]

Reid, J. S., R. Koppmann, T. Eck, and D. Eleuterio A Review of Biomass Burning Emissions Part II: Intensive Physical Properties of Biomass Burning Particles, *Atmos. Chem. Phys.,* 5, 799–825, SRef-ID: 1680-7324/acp/2005-5-799, 2005. http://www.atmos-chem-phys.org/acp/5/799/ [published, refereed]

Reid, J. S., T. Eck, S. Christopher, O. Dubovik, R. Koppmann, D. Eleuterio, B. Holben, E. Reid, and J. Zhang, A Review of Biomass Burning Emissions Part III: Intensive Optical Properties of Biomass Burning Particles, Atmos. Chem. Phys., 5, 827–849, SRef-ID: 1680-7324/acp/2005-5-827, 2005. http://www.atmos-chem-phys.org/acp/5/827/ [published, refereed]

Zhang, J., J. S.Reid, and B. N. Holben (2005), An analysis of potential cloud artifacts in MODIS over ocean aerosol optical thickness products, Geophys. Res. Lett., 32, doi:10.1029/2005GL023254, 2005. [published, refereed]

(b) Conferences, Abstracts, and Other Publications

Reid, J.S., T. Eck, J. Zhang, R. Koppmann, N. O'Neill A critical review of smoke particle evolutionary processes, Eos Trans. Suppl., 85, (47), Fall Meeting Suppl., Abstract A34B-04, 2004.

Eck., T.F., B. N. Holben, J. Boonjawat, H. V. LKee, L. A. Remer, J. S. Schafer, J. S. Reid, O. Dubovik, and A. Smirnov, Aerosol Optical Properties in Southeast Asia and Comparison of MODIS

Optical Depth Retrievals to AERONET Measurements, Eos Trans. Suppl., 85, (47), Fall Meeting Suppl., Abstract A33D-0090, 2004.

Honrath, R. E., R. C. Owen, M. Val Mart, J. S. Reid, K. Lapina. J. P. Kleissl, and P. Fialho, Ozone-CO relationships in plumes carrying North American pollution and boreal biomass burning emissions through the central North Atlantic lower free troposphere, Eos Trans. Suppl., 85, (47), Fall Meeting Suppl., Abstract A23A-0769, 2004.

Wang, J., S. A. Christopher, U. S. Nair, J. S. Reid, E. M. Prins, The Effect of Central American Smoke Aerosols on the Air Quality and Climate over the Southeastern United States: First Results from RAMS-AROMA, Eos Trans. Suppl., 85, (47), Fall Meeting Suppl., Abstract A11A-0022, 2004.

Welton, E. J., J. R. Campbell, J. D. Spinhirne, T.A. Berkoff, B. Holben, S. Tsay, A. Bucholtz, E. Reid, An Aerosol Extinction-to-Backscatter Ratio Database Derived from the NASA Micro-Pulse Lidar Network: Applications for Space-based Lidar Observations, Eos Trans. Suppl., 85, (47), Fall Meeting Suppl., Abstract A11C-0081, 2004.

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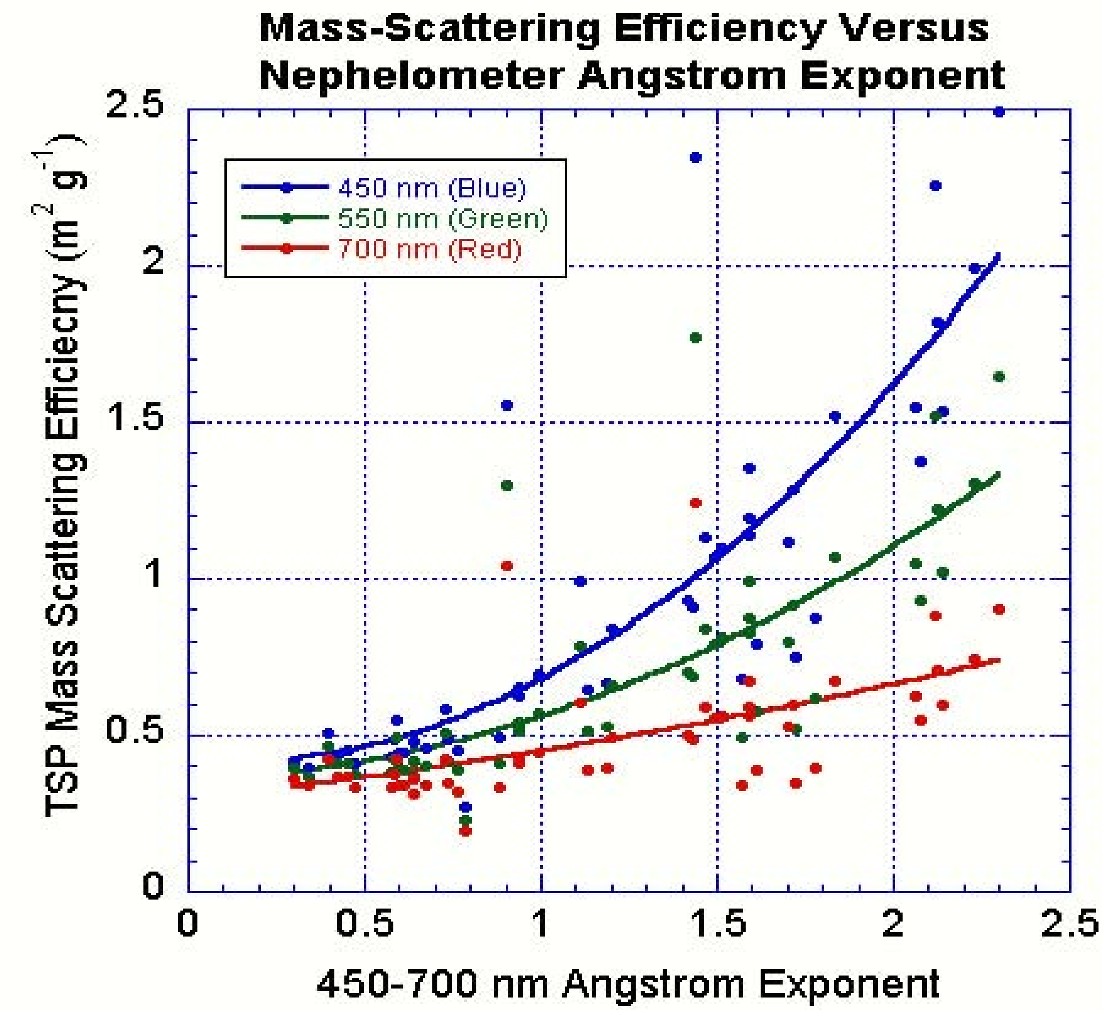

Figure 1. Particle mass scatterign efficiency as a fucntion of Angstrom Exponent. Angstrom Exponents above 2 imply light scattering is almost enitrely by small polllution particles. Converely, values les than 0.5 imply only dust.

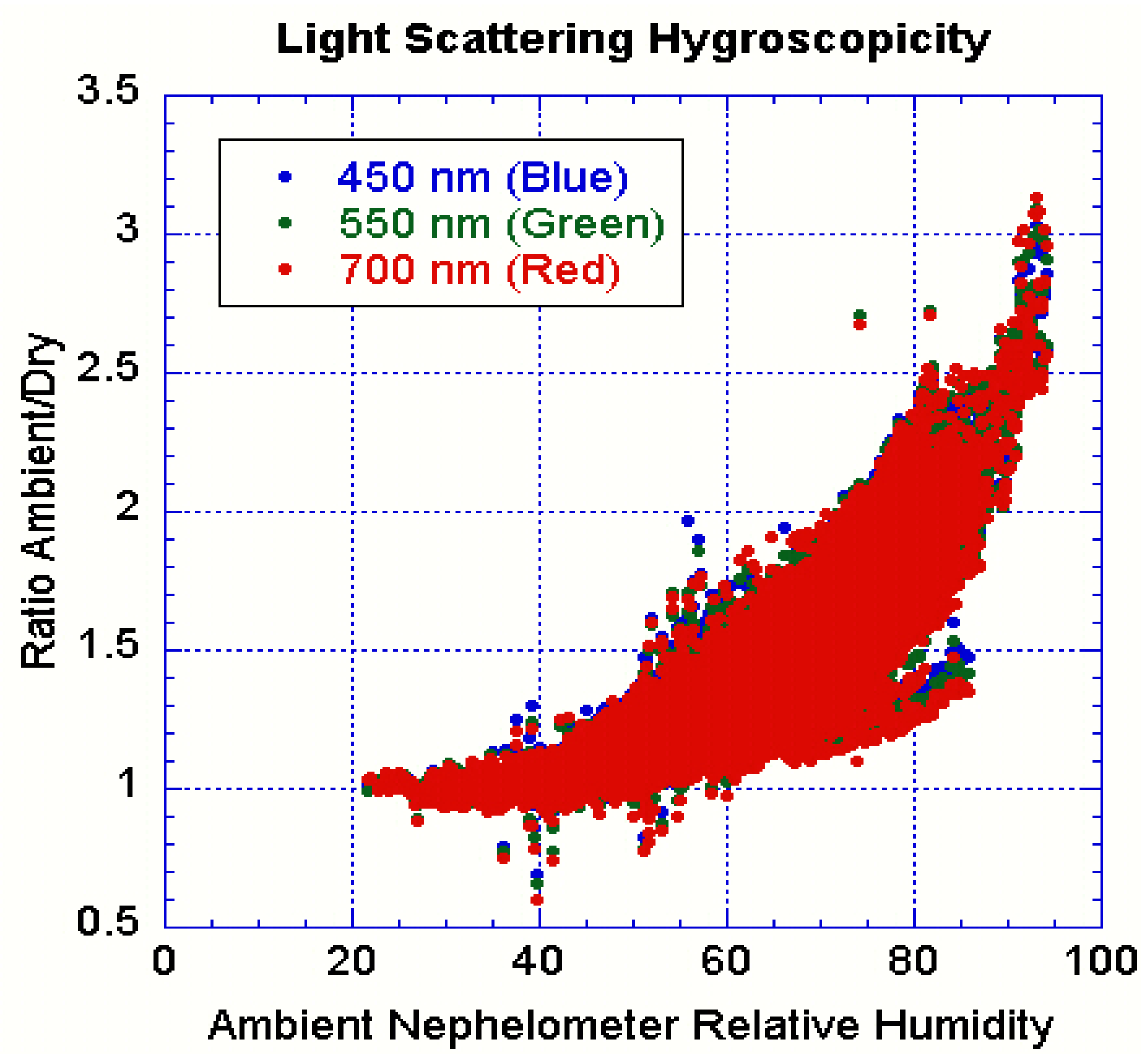

Figure 2. Particle light scattering efficincy (ratio of light scattering at ambient relative humidity to dry) for the entire UAE2 mission.

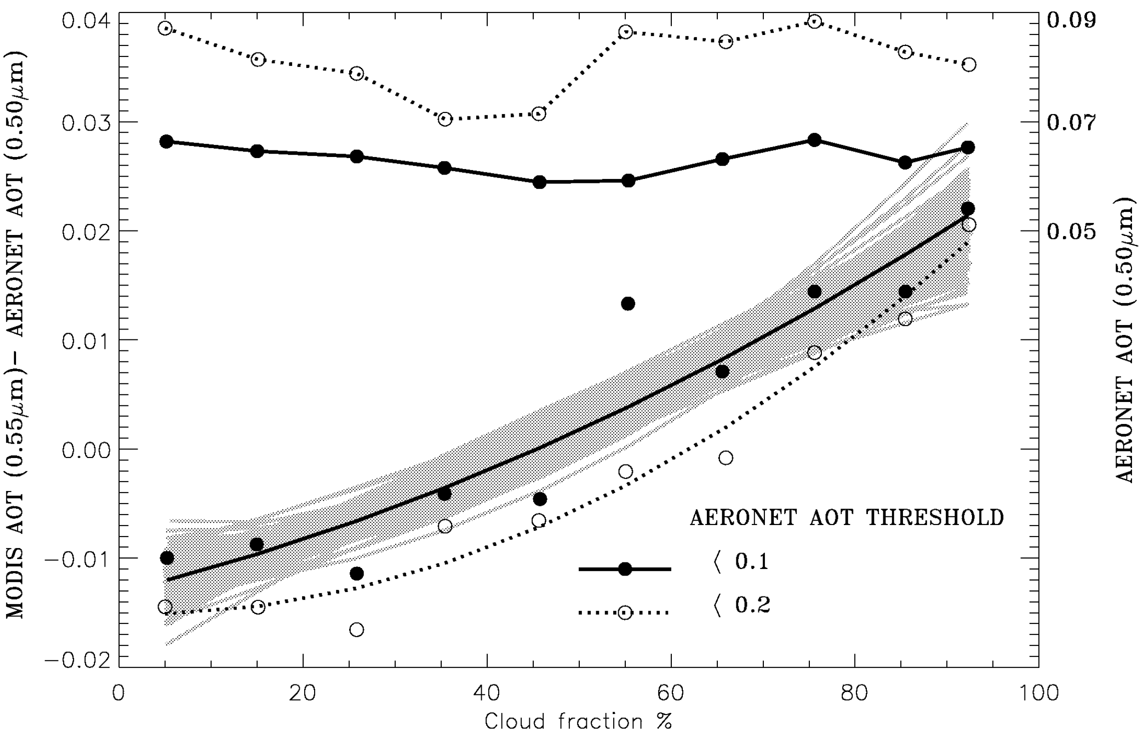

Figure 3. Lower curves: the difference in MODIS and sun-photometer τ vs. cloud fraction; Upper portion showed the averaged sun-photometer $\tau_{0.50\mu m}$ vs. cloud fraction. Sicne the upper curves are flat, the MODIS standard product must me biased do to impropper screenign of clouds

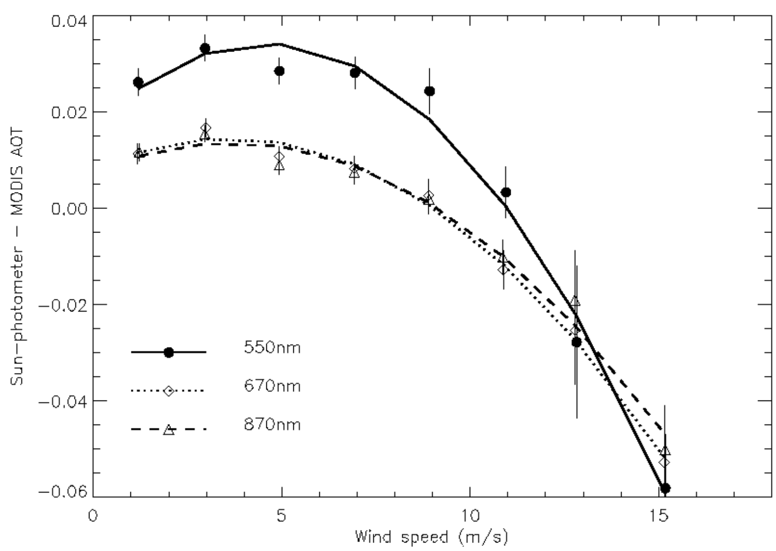

Figure 4. Difference between sun photomter (true) and MODIS derived optical depth as a fucntion of wind speed.

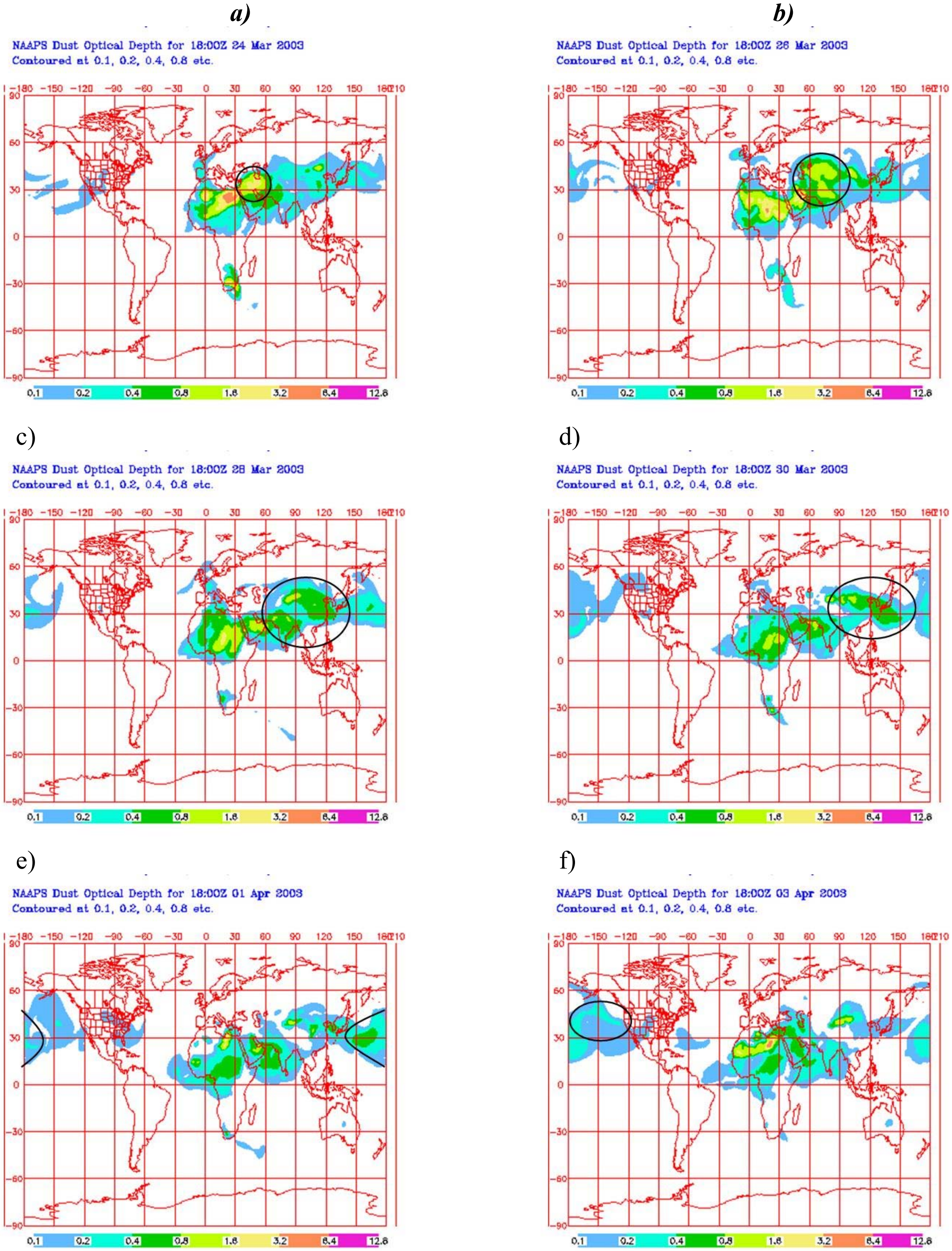

Figure 5. NAAPS model run showing the progression of southwest Asian dust to the west coast of the United States.